

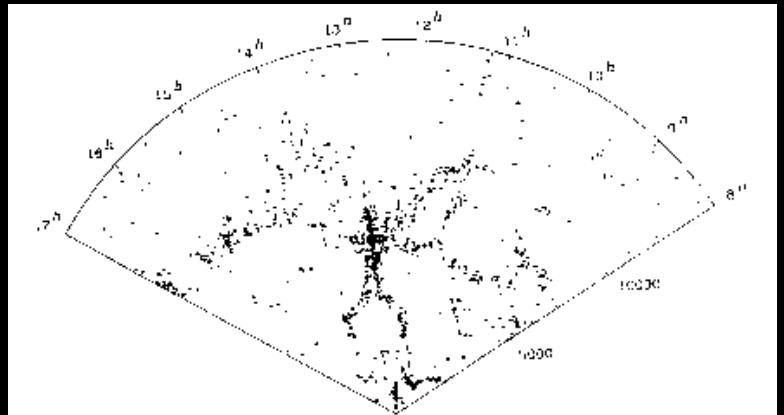
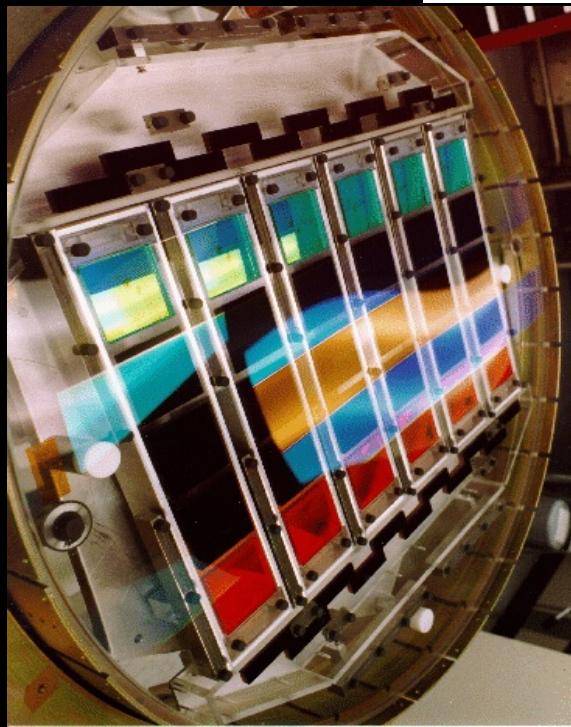
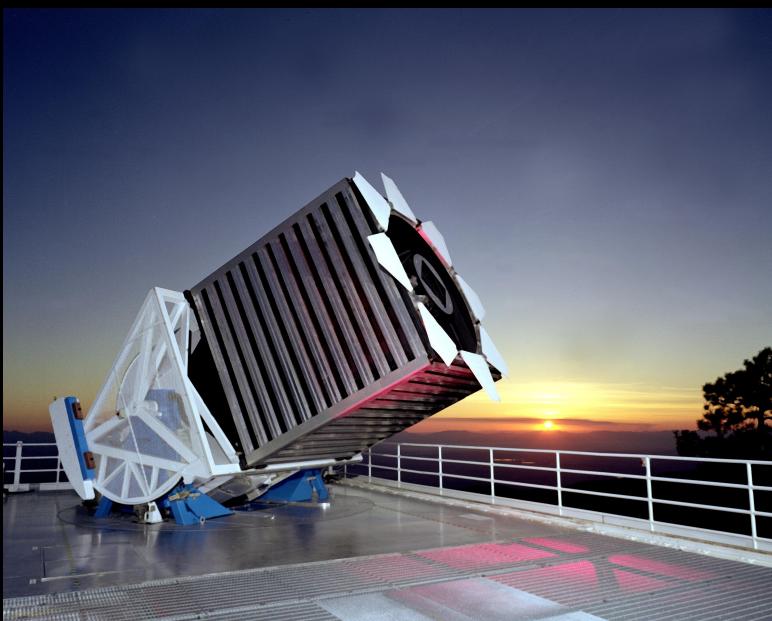
# Observational Cosmology at Fermilab:

*Sloan Digital Sky Survey*  
*Dark Energy Survey*  
**SNAP**

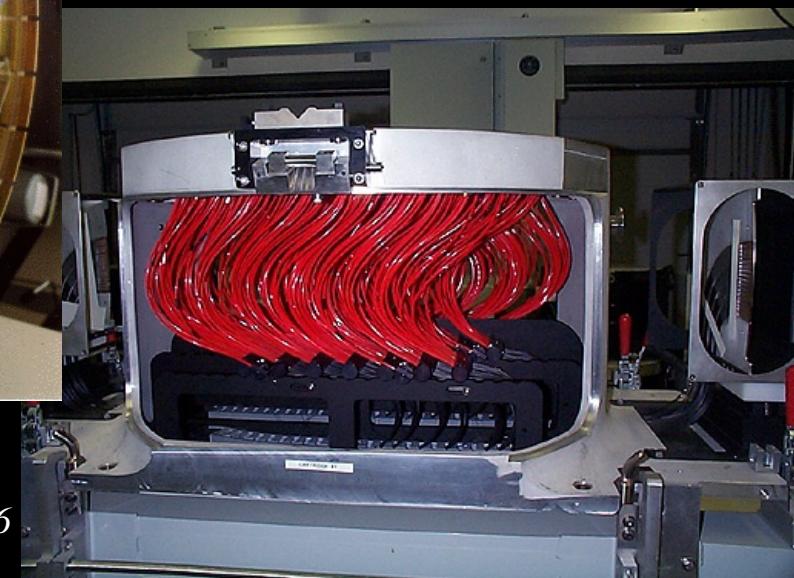
*Gajus Miknaitis*  
*Fermilab Users Meeting*  
*May 31, 2006*

# Sloan Digital Sky Survey (SDSS)

Motivation: study the distribution of matter in the universe by measuring the distribution of galaxies in space (2D + redshift)

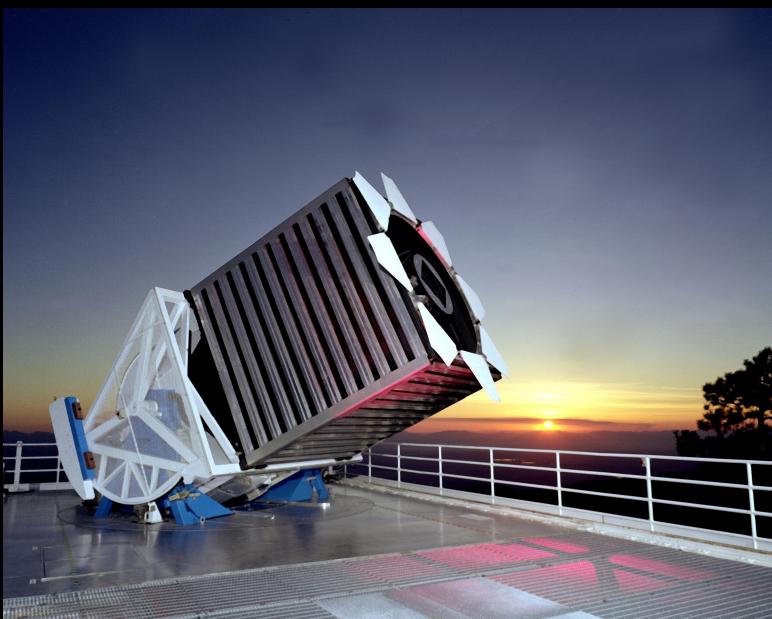


*CfA Redshift Survey (1986)*

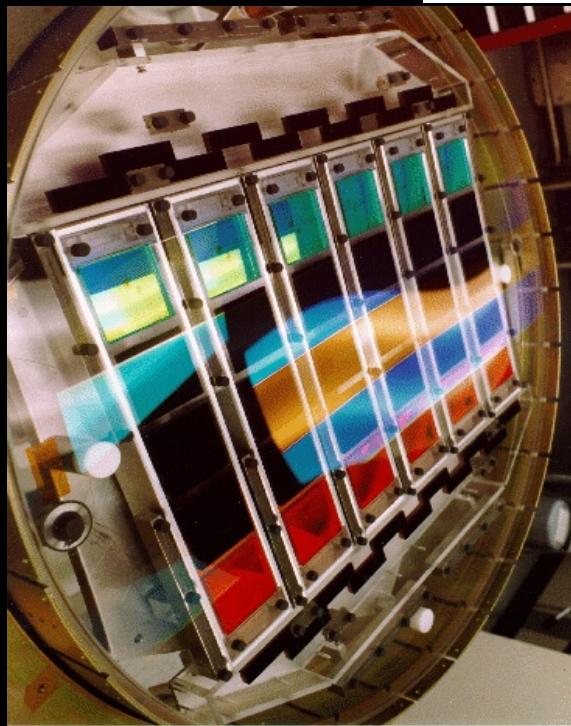


# Sloan Digital Sky Survey (SDSS)

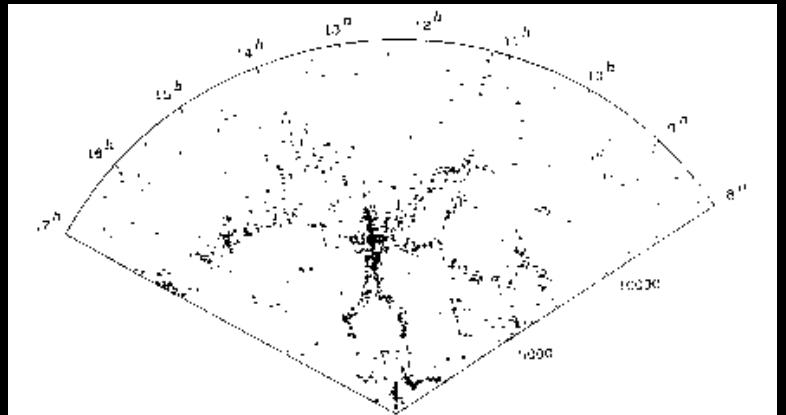
Motivation: study the distribution of matter in the universe by measuring the distribution of galaxies in space (2D + redshift)



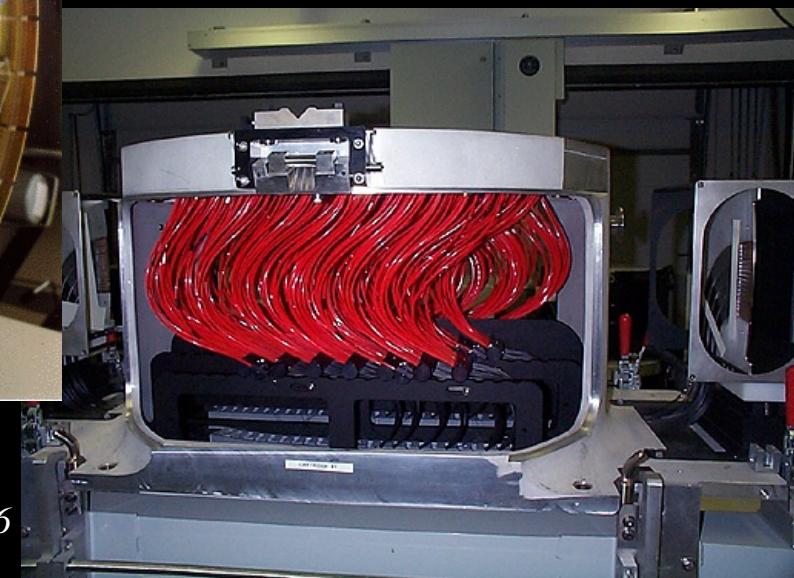
Imaging camera: →  
find galaxies, measure  
their angular positions



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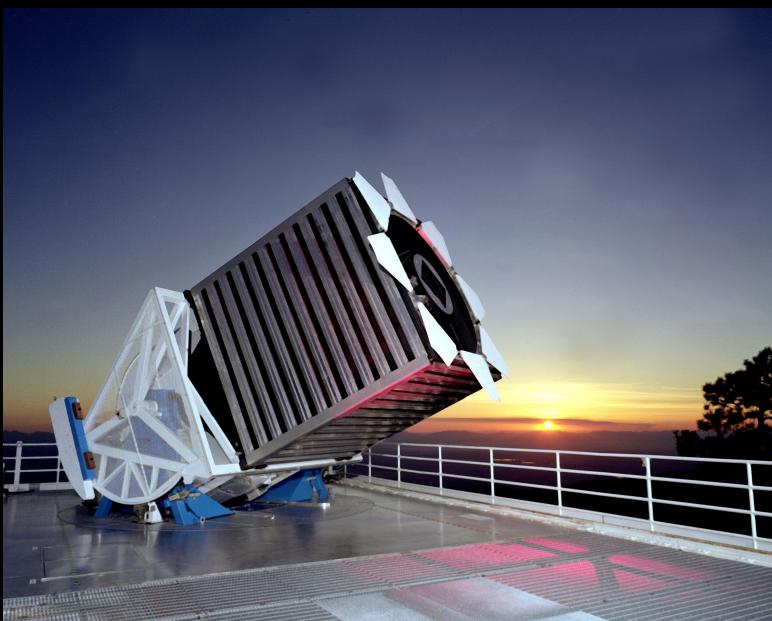


CfA Redshift Survey (1986)



# Sloan Digital Sky Survey (SDSS)

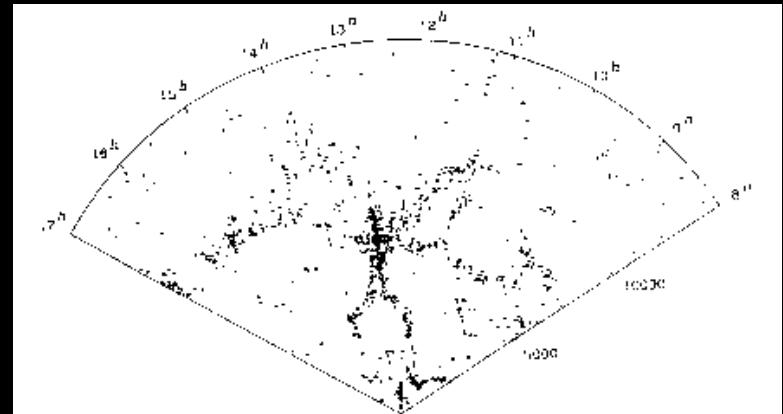
Motivation: study the distribution of matter in the universe by measuring the distribution of galaxies in space (2D + redshift)



Imaging camera: →  
find galaxies, measure  
their angular positions

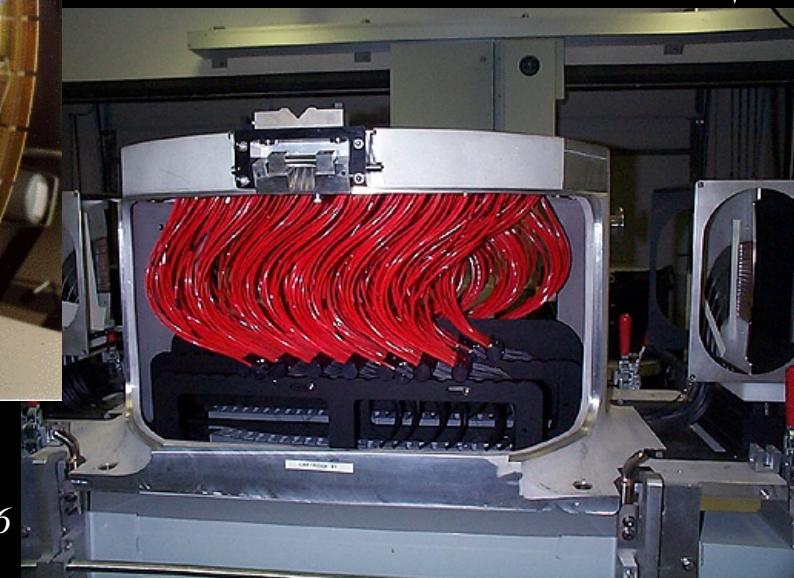


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CfA Redshift Survey (1986)

Multi-object spectrograph:  
measure galaxy redshifts  
distance  $\approx$  redshift



# SDSS data set

**After ~5 years of operation, SDSS has:**

- imaged more than 8,000 square degrees of the sky in five bandpasses
  - detected nearly 200 million celestial objects
- measured spectra of more than 675,000 galaxies, 90,000 quasars, and 185,000 stars



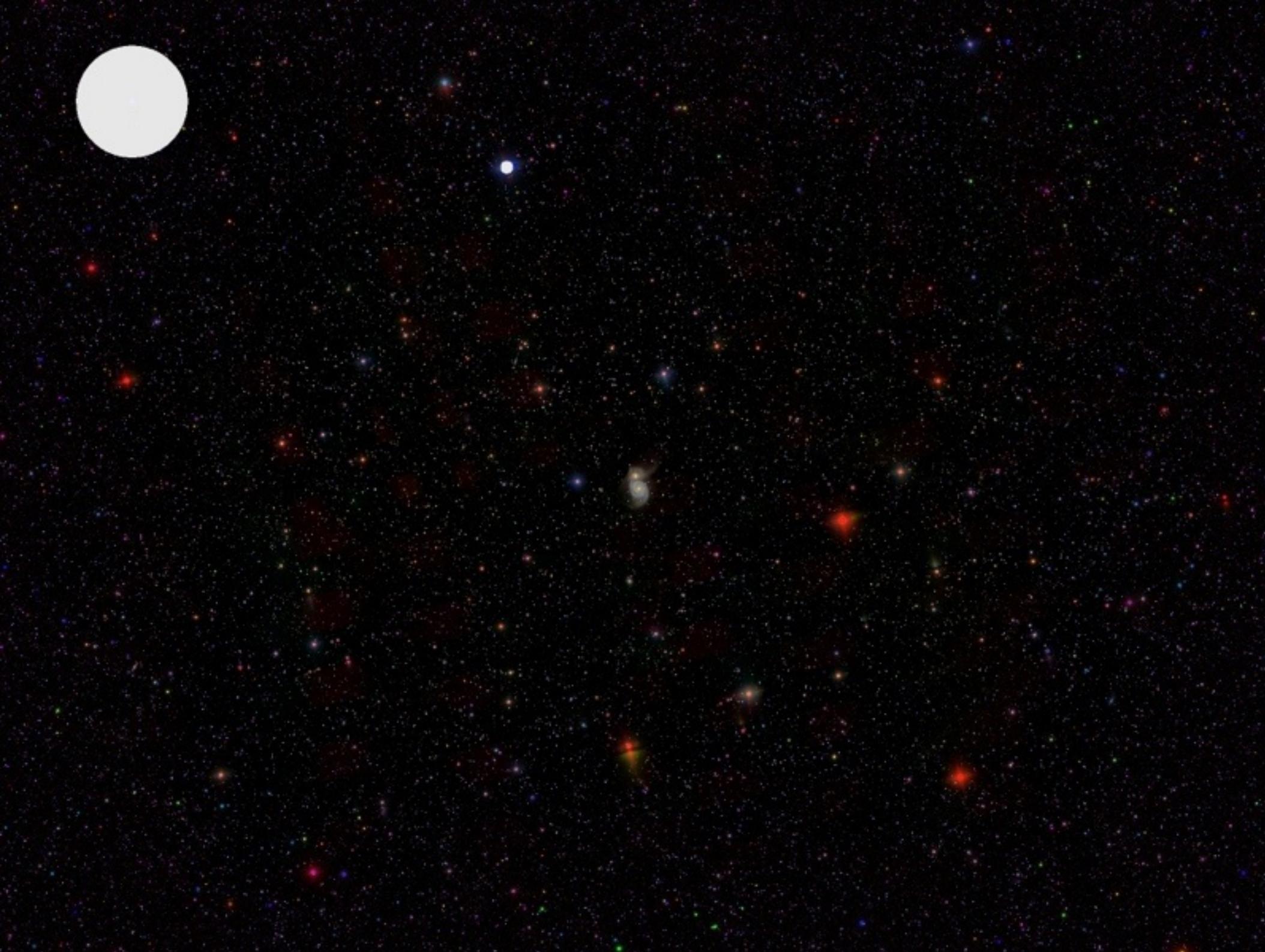














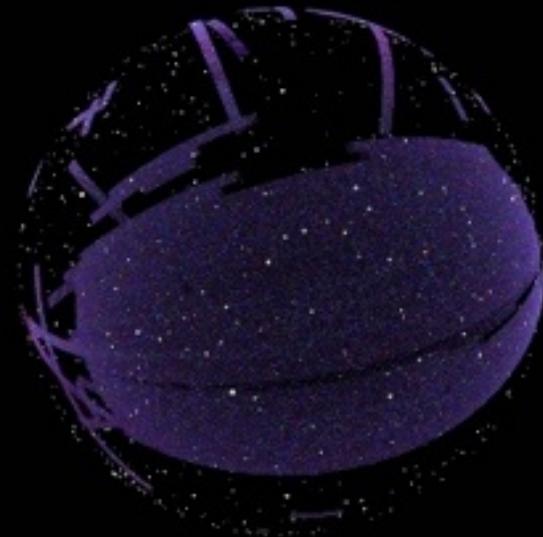






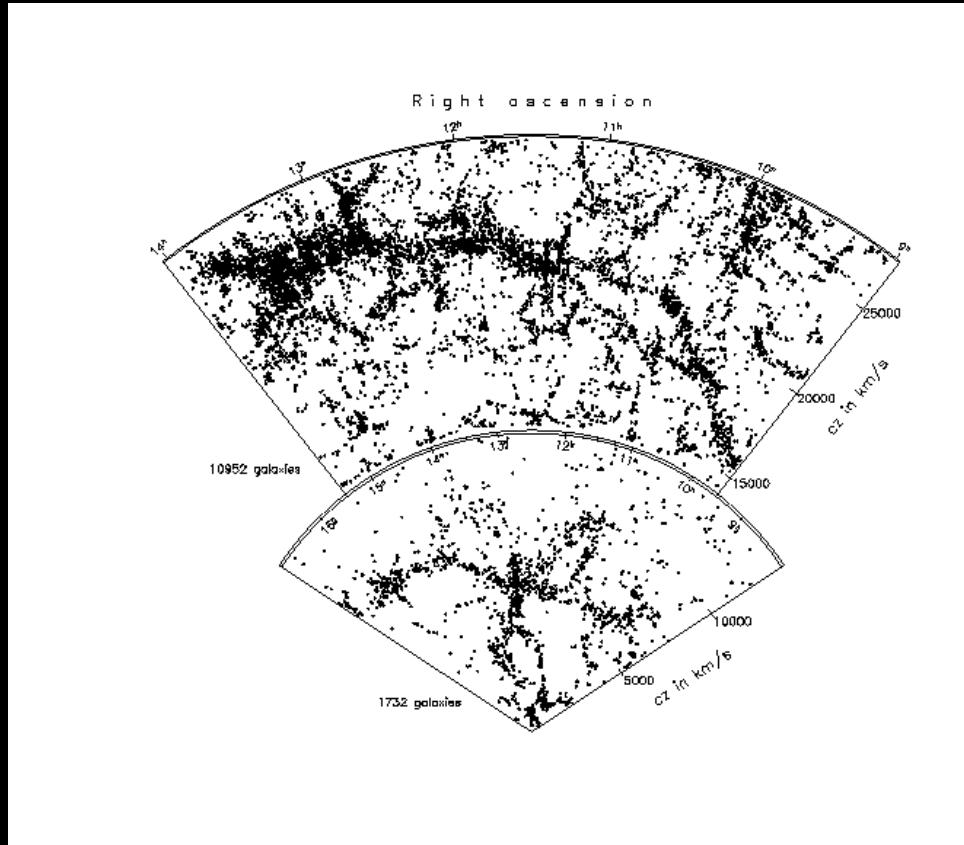


**data: Sloan Digital Sky Survey  
and the Bright Star Catalog**

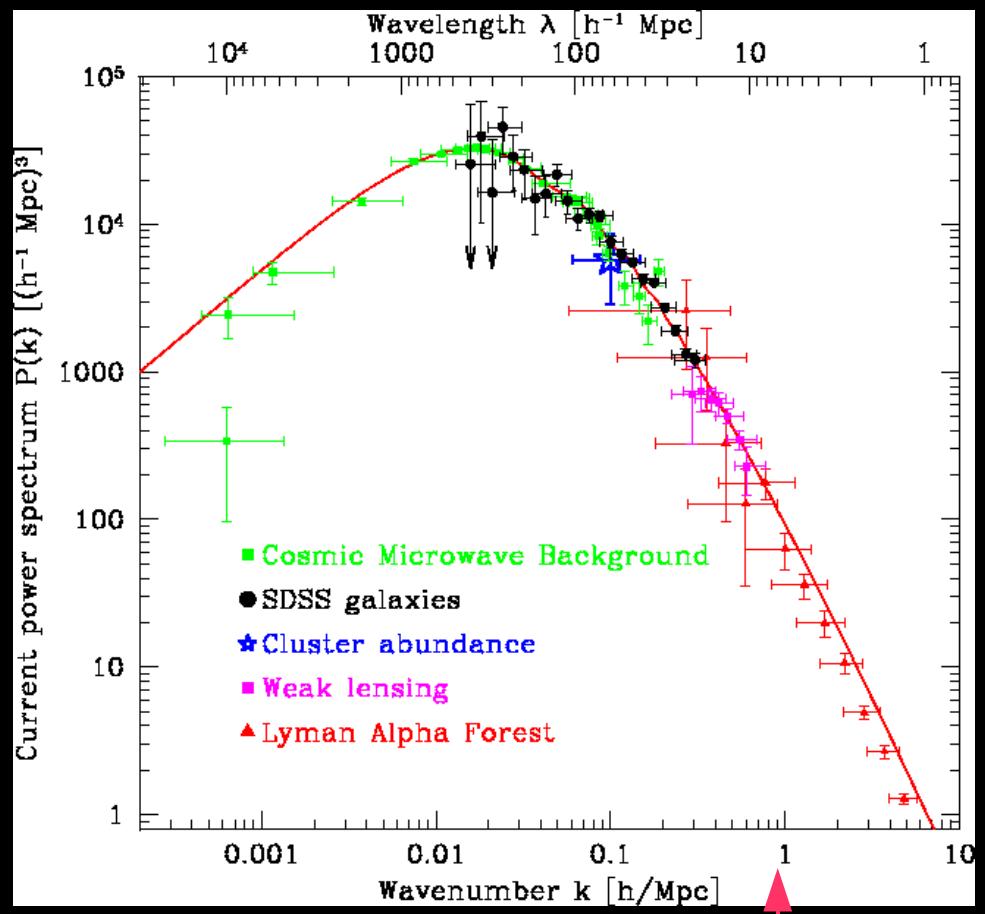


**visualization: David W. Hogg (NYU)  
with help from Blanton, Finkbeiner,  
Padmanabhan, Schlegel, Wherry**

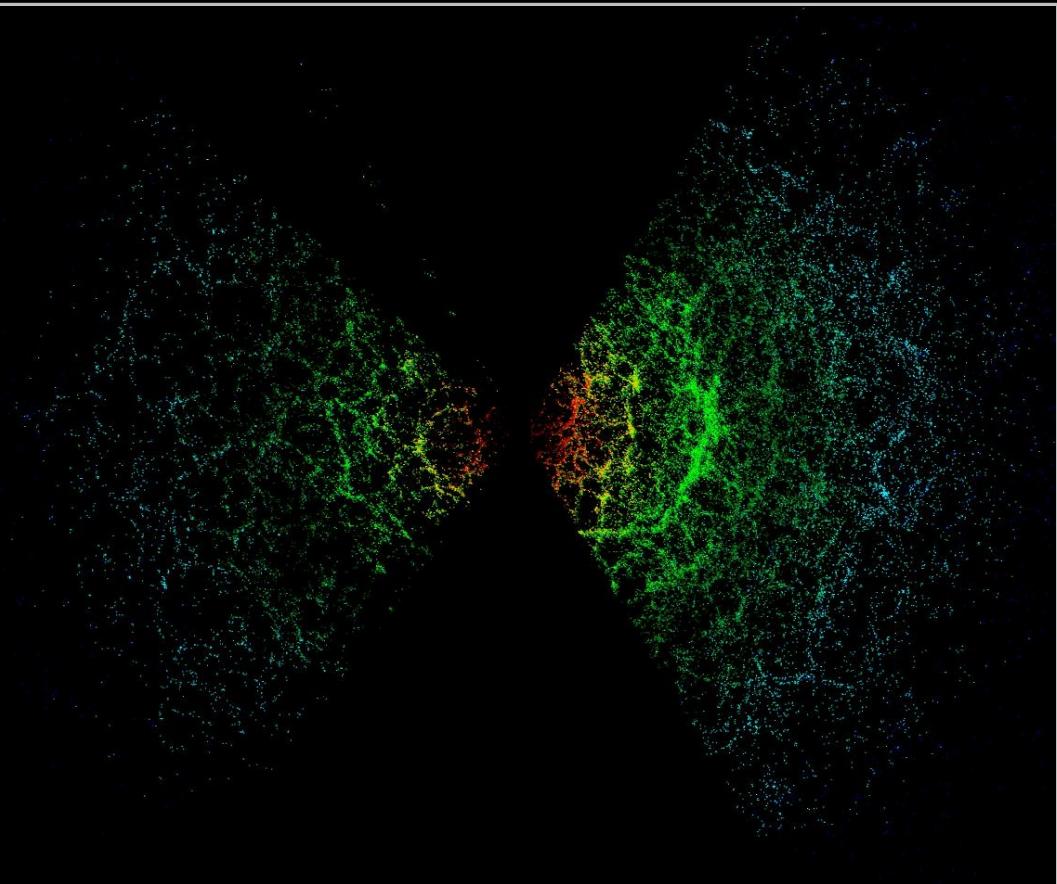
# SDSS & Large Scale Structure



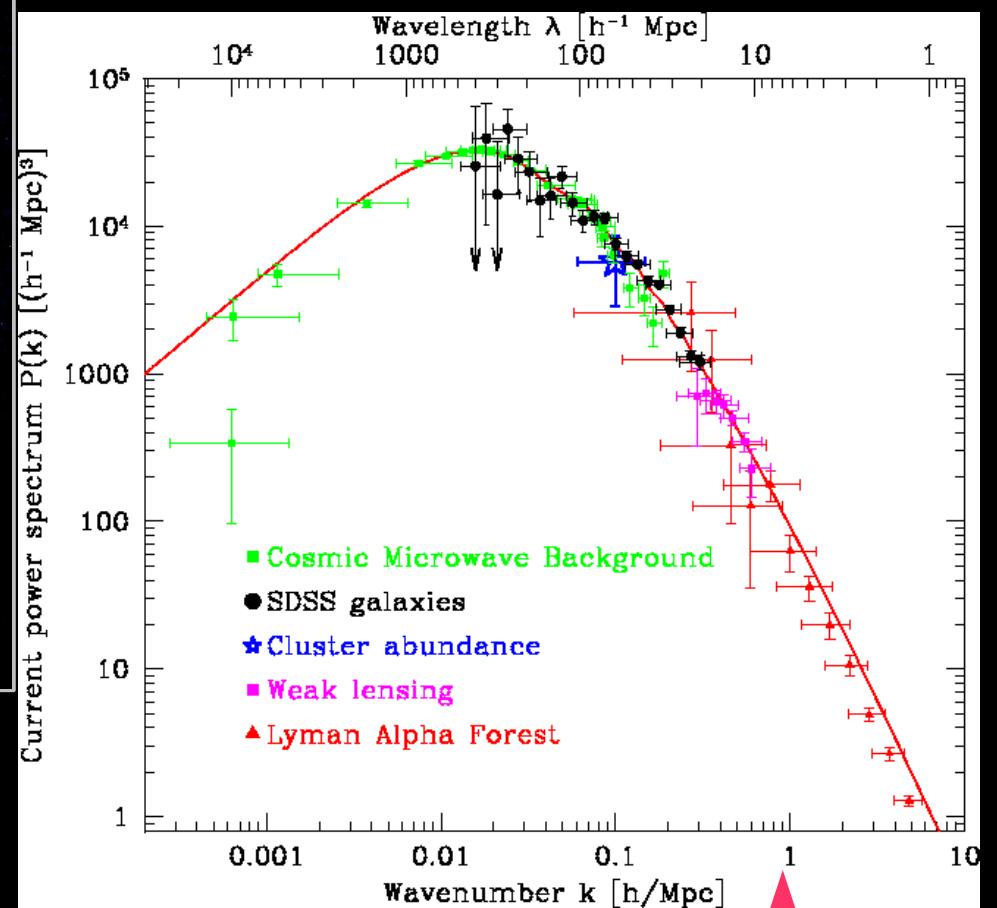
power spectrum of matter



# SDSS & Large Scale Structure



power spectrum of matter



# Scientific impact of the SDSS

- As of May 30, 2006, **1080** refereed, published papers mention SDSS, “Sloan Survey” or make use of SDSS data
- Over 31,000 citations of these papers in the literature.
- 22 SDSS papers with more than 200 citations

## Some science highlights

- State-of-the-art **Large Scale Structure** measurements
  - 3D power spectrum of matter
  - detection of baryonic acoustic oscillations
- Catalog of  $10^5$  **quasars** out to  $z \approx 7$
- Reionization of the universe at  $z=7$  (Gunn-Peterson effect)
- Catalog of  $10^6$  **galaxy clusters** to  $z=0.5$
- **Tidal tails** and stellar streams in our galaxy
- Discovery of many rare low-mass **dwarf stars**
- etc, etc!

*G. Miknaitis*

*FNAL Users Meeting, May 31, 2006*

# SDSS II: The Sequel

SDSS I: april 2000 - june 2005  
*completed*

SDSS II: july 2005 - july 2008



# SDSS collaboration

~150 scientists from

**Am. Museum Nat. History**

**Astrophysical Inst. Potsdam**

**U. Basel**

**Cambridge U.**

**Case Western Reserve**

**U. Chicago**

**Drexel U.**

**Fermilab**

**Institute for Adv. Studies**

**Japanese Participation Grp**

**Johns Hopkins U.**

**JINA**

**Kavli Institute for Particle Astrophysics**

**Korean Scientist Group**

**LAMOST (China)**

**Los Alamos Nat. Lab**

**Max Planck Inst. Astron.**

**Max Planck Inst. Astrophy.**

**New Mexico State U.**

**Ohio State U.**

**U. Pittsburgh**

**U. Portsmouth**

**Princeton U.**

**US Naval Obs.**

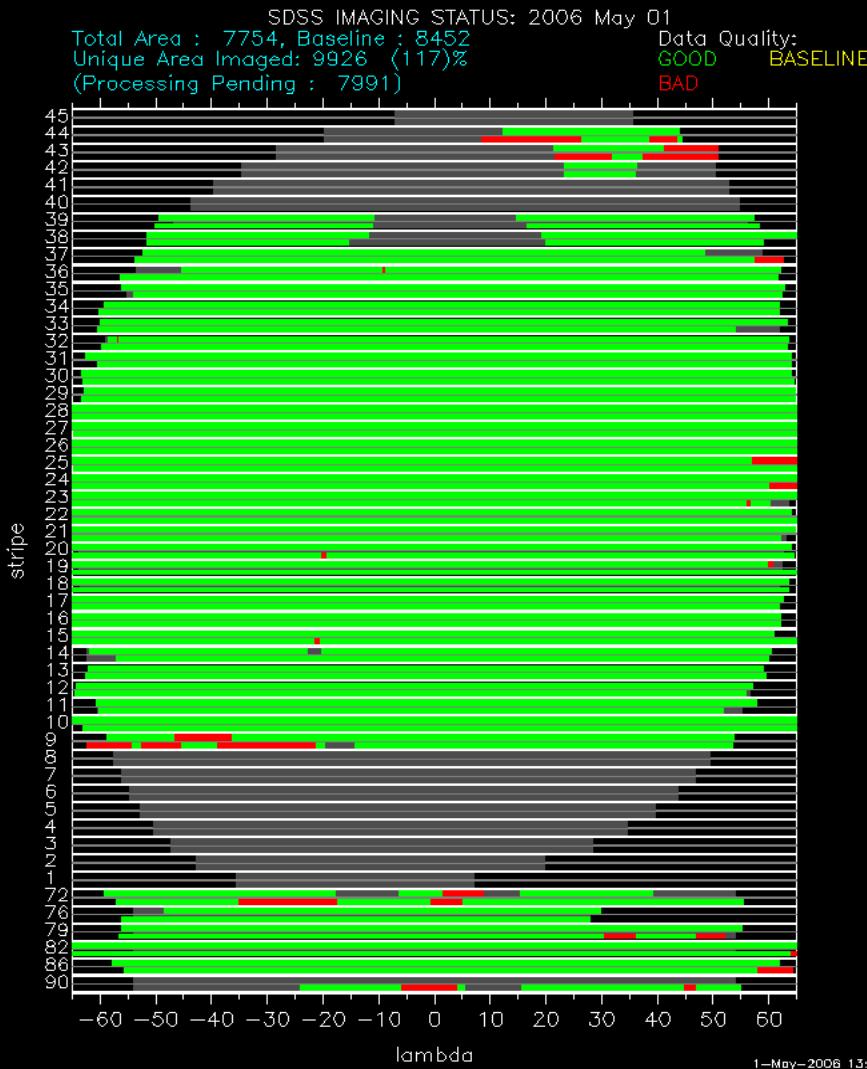
**U. Washington**

# SDSS II: components

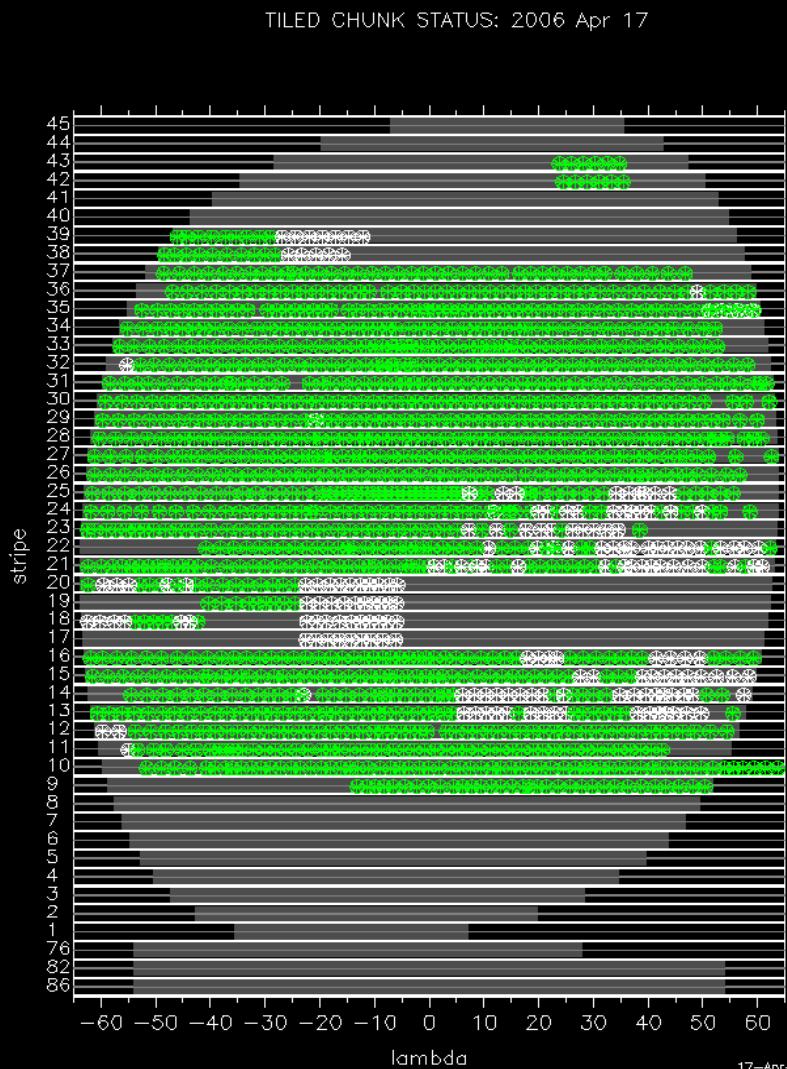
1. **SDSS “legacy”**: complete the original imaging and spectroscopy survey
2. **SEGUE**: study the (dark matter) halo of the Milky Way
3. **Supernovae**: survey to discover  $\sim 200$  SNe to probe the expansion history of the universe (dark energy)

# 1. SDSS “legacy”

Imaging is complete  
(gap filled)

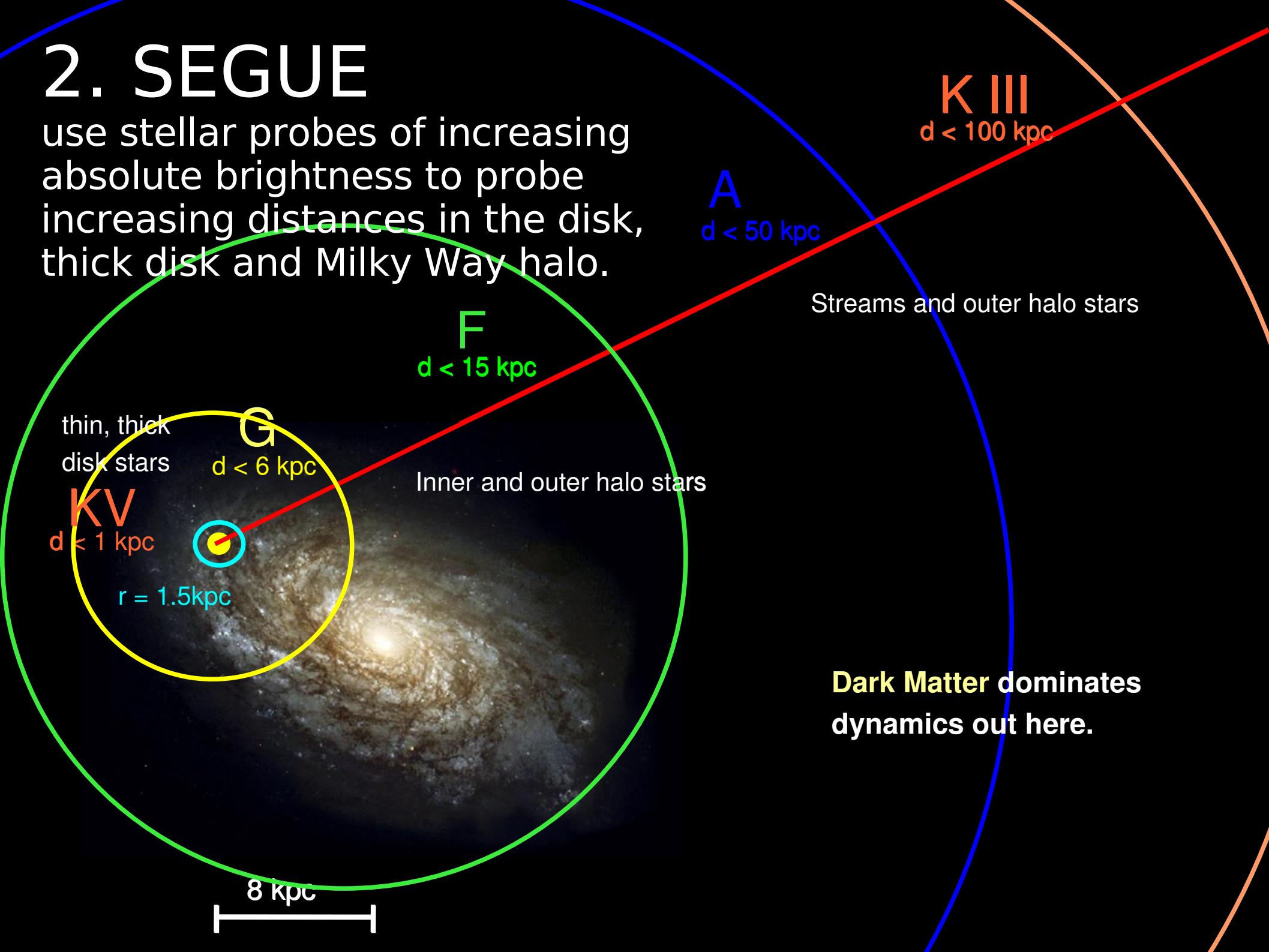


Spectroscopy on track  
(two years left)



## 2. SEGUE

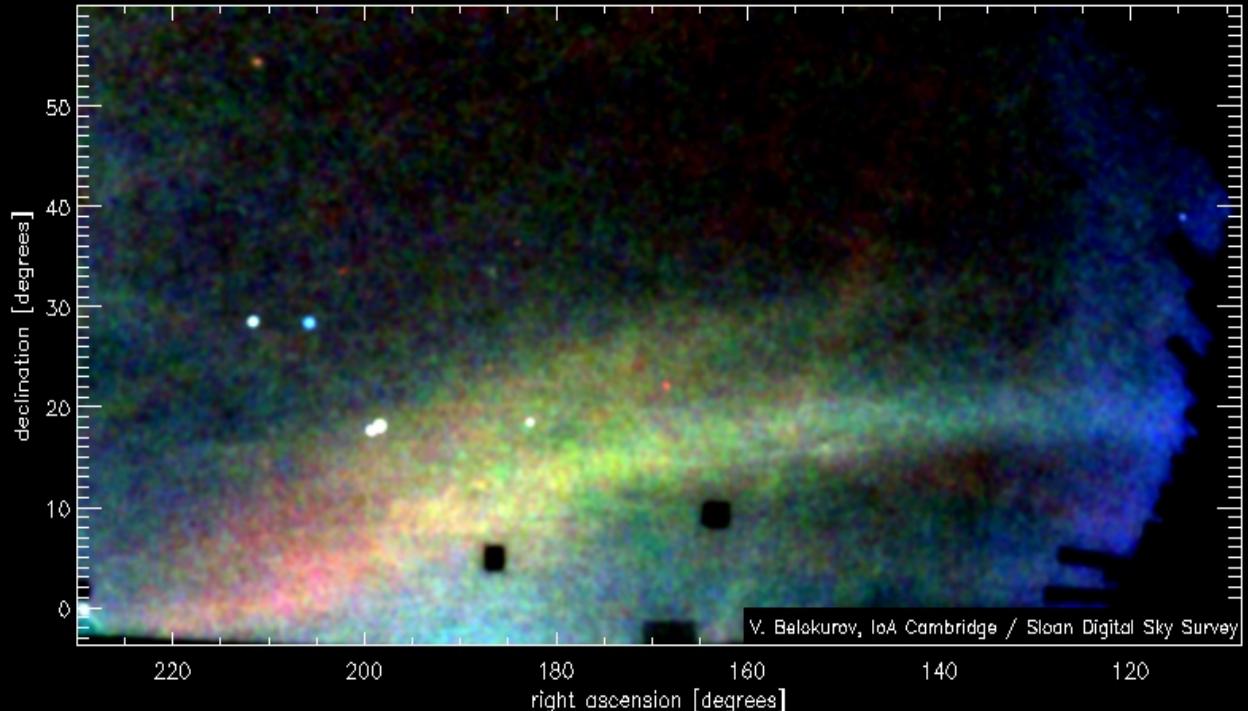
use stellar probes of increasing absolute brightness to probe increasing distances in the disk, thick disk and Milky Way halo.





# Star streams as probes of Dark Matter!

density of F stars in a  
patch on the sky,  
color-coded by their  
brightness



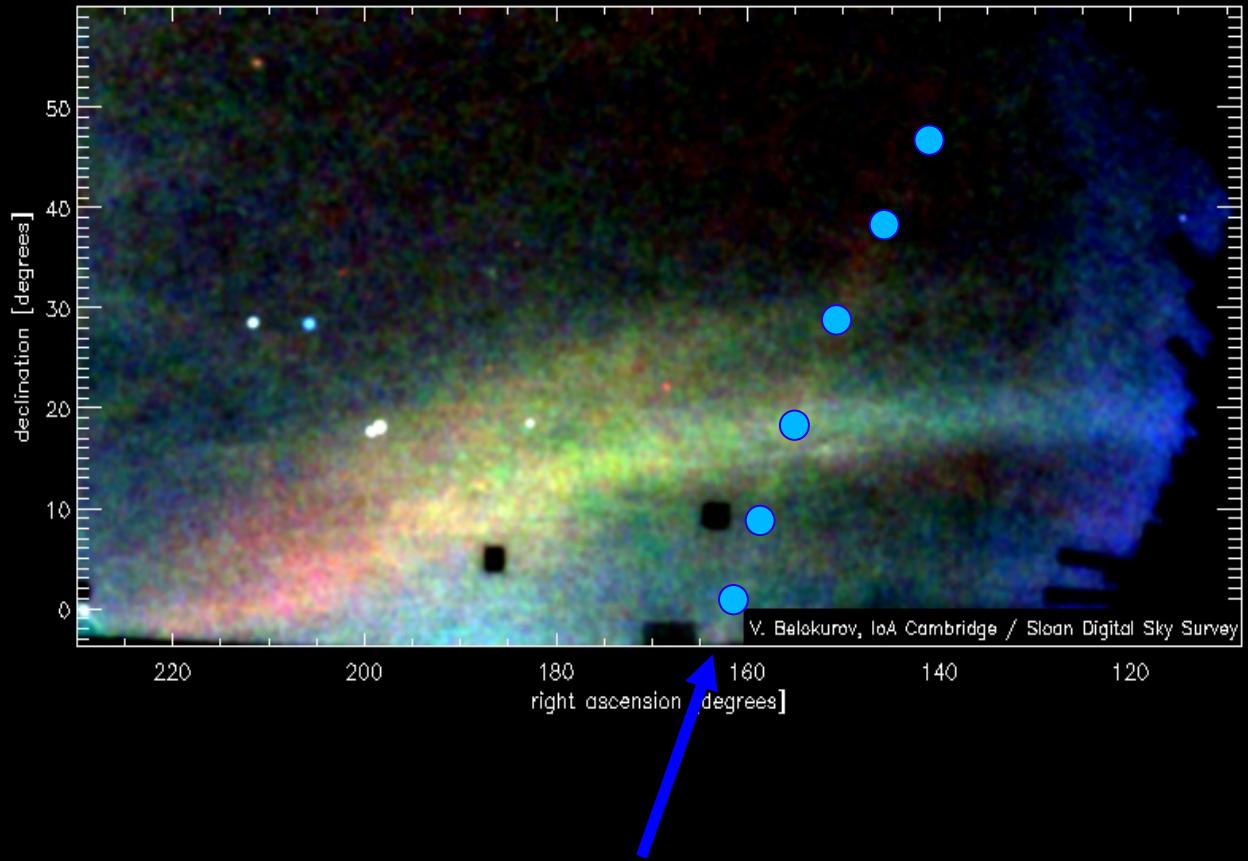
*G. Miknaitis*

*FNAL Users Meeting, May 31, 2006*



# Star streams as probes of Dark Matter!

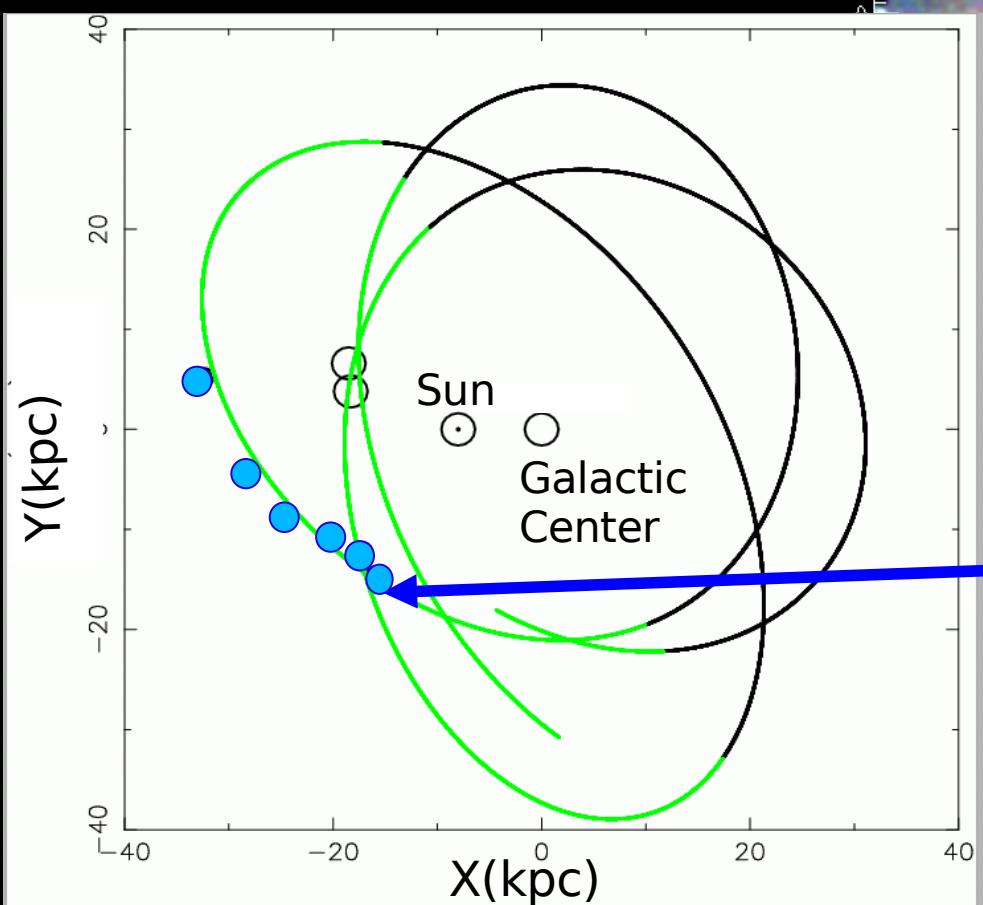
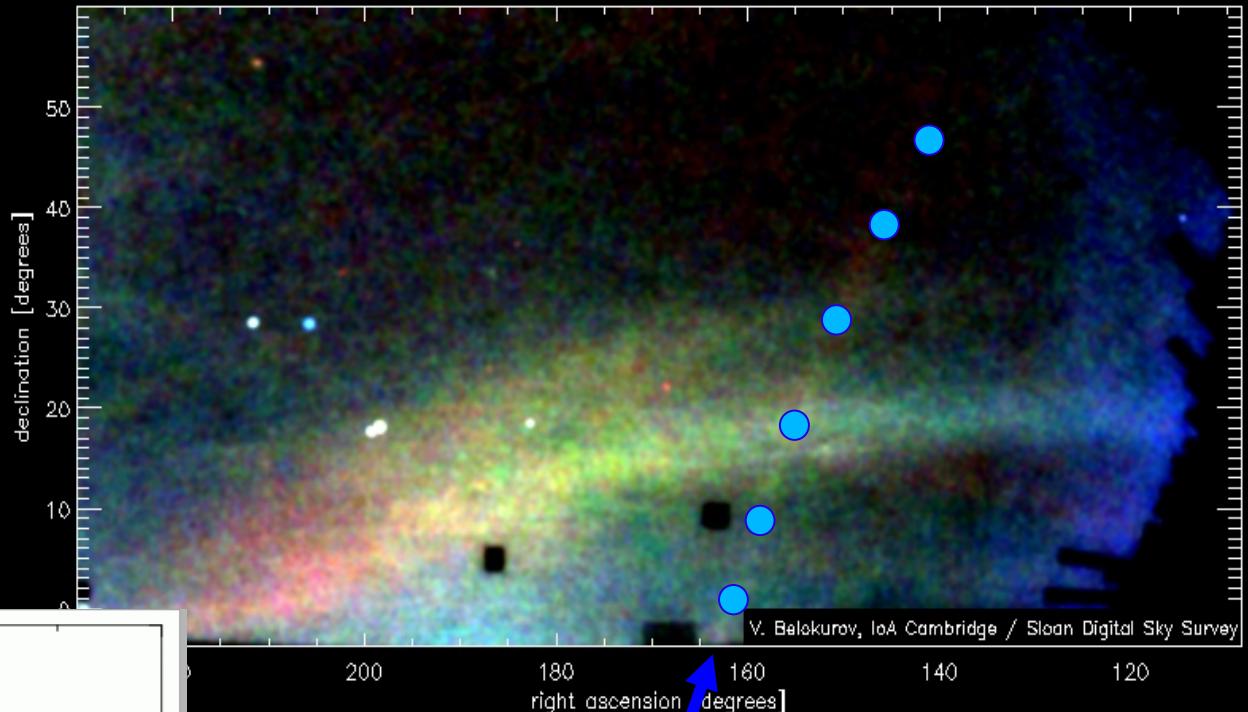
density of F stars in a  
patch on the sky,  
color-coded by their  
brightness





# Star streams as probes of Dark Matter!

density of F stars in a  
patch on the sky,  
color-coded by their  
brightness



Newly discovered 'orphan stream'!

Fitting the orbit of this stream  
in 3-D can constrain the shape of  
the Dark Matter Halo surrounding  
our Milky Way Galaxy.

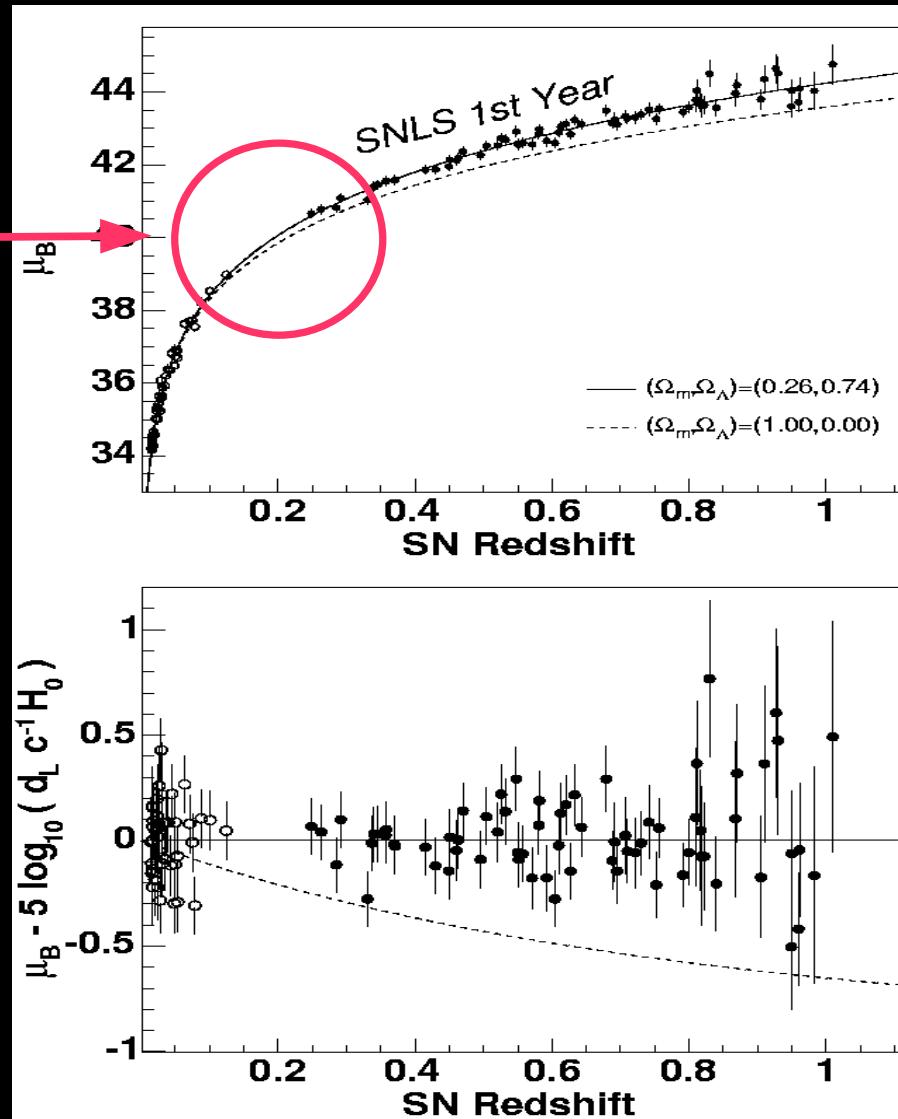
Fit is consistent with a spherical halo

# 3. Supernovae & Dark Energy

- Type Ia supernovae are **standard(izable) candles**.
- By measuring their brightness and cosmological redshift, we can trace the **expansion rate** & thus infer the **make-up** of the universe as a function of time.
- Initial SN experiments found surprisingly that the universe appears to be **speeding up**, fueled by gravitationally repulsive “**dark energy**”.

# 3. SDSS II Supernovae

- SDSS well-suited to finding SNe at *moderate redshifts* that are difficult for other experiments
- Build up **large (~200)** sample of well-observed supernovae to study dark energy and better understand the supernova population
- Study *systematics* which are increasingly important with larger samples



Astier '06

G. Miknaitis

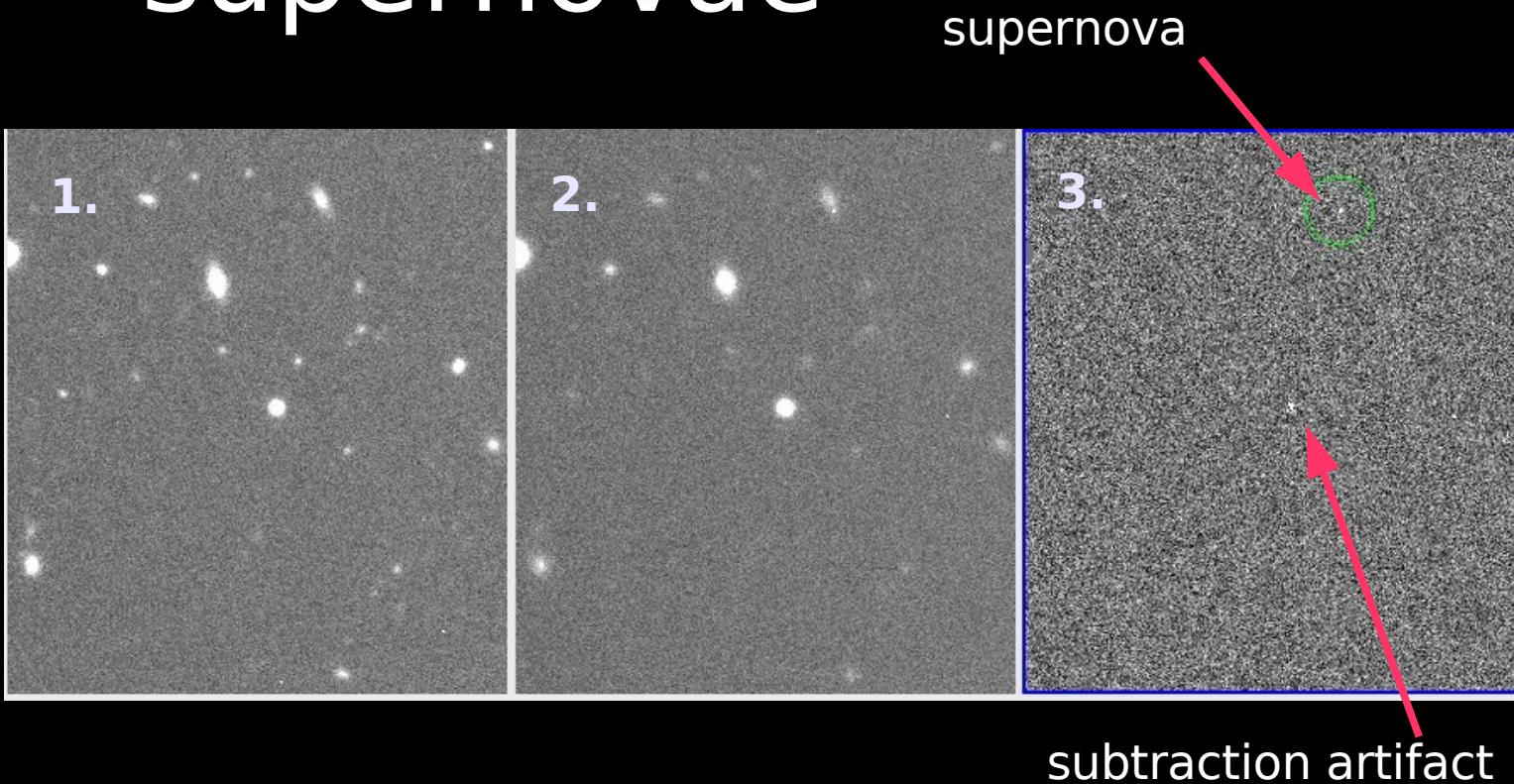
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# Finding and measuring supernovae

1. Take an image

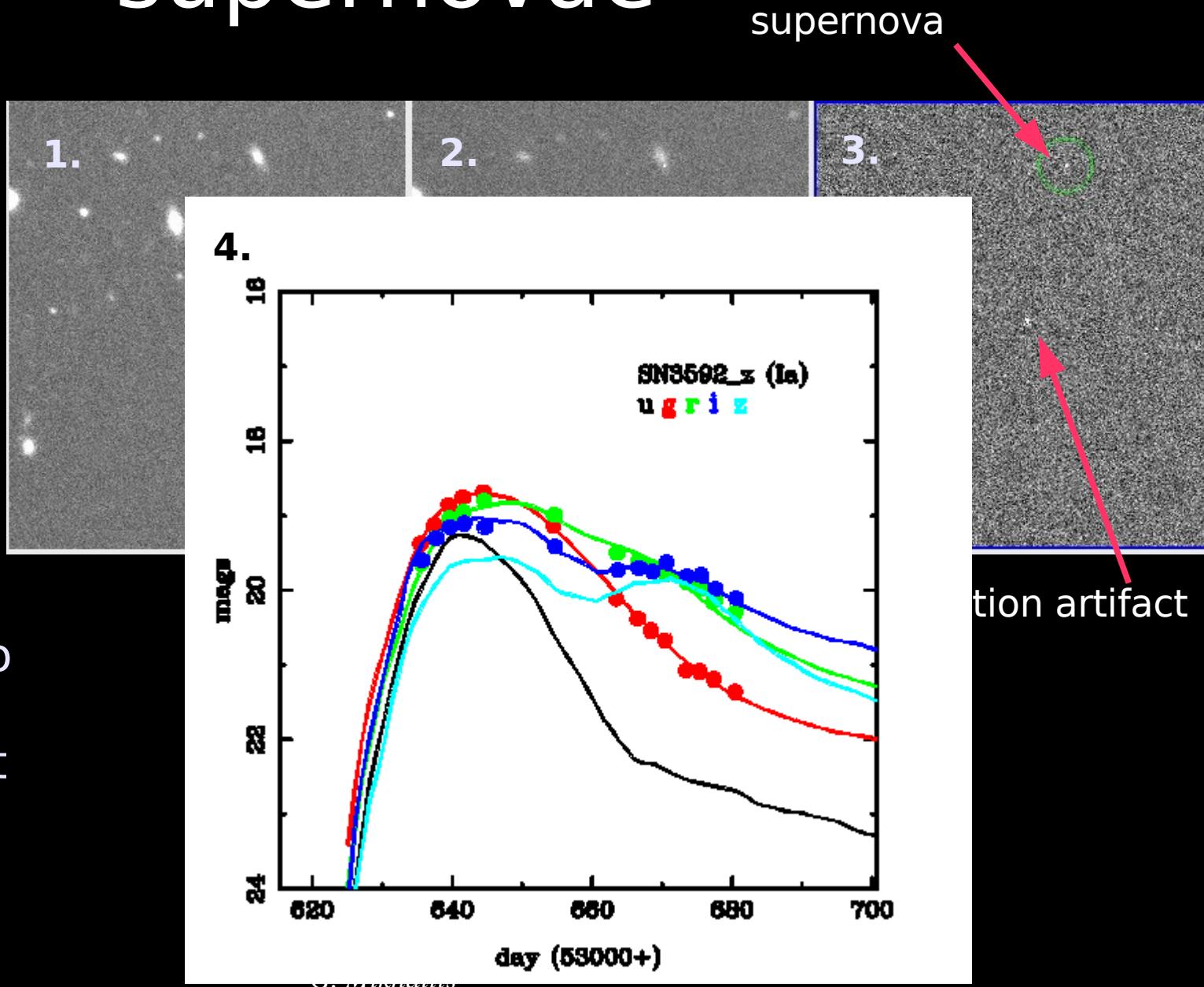
2. Take another image later

3. Subtract the two



# Finding and measuring supernovae

1. Take an image
2. Take another image later
3. Subtract the two
4. Continue taking images to measure supernova “light curve”

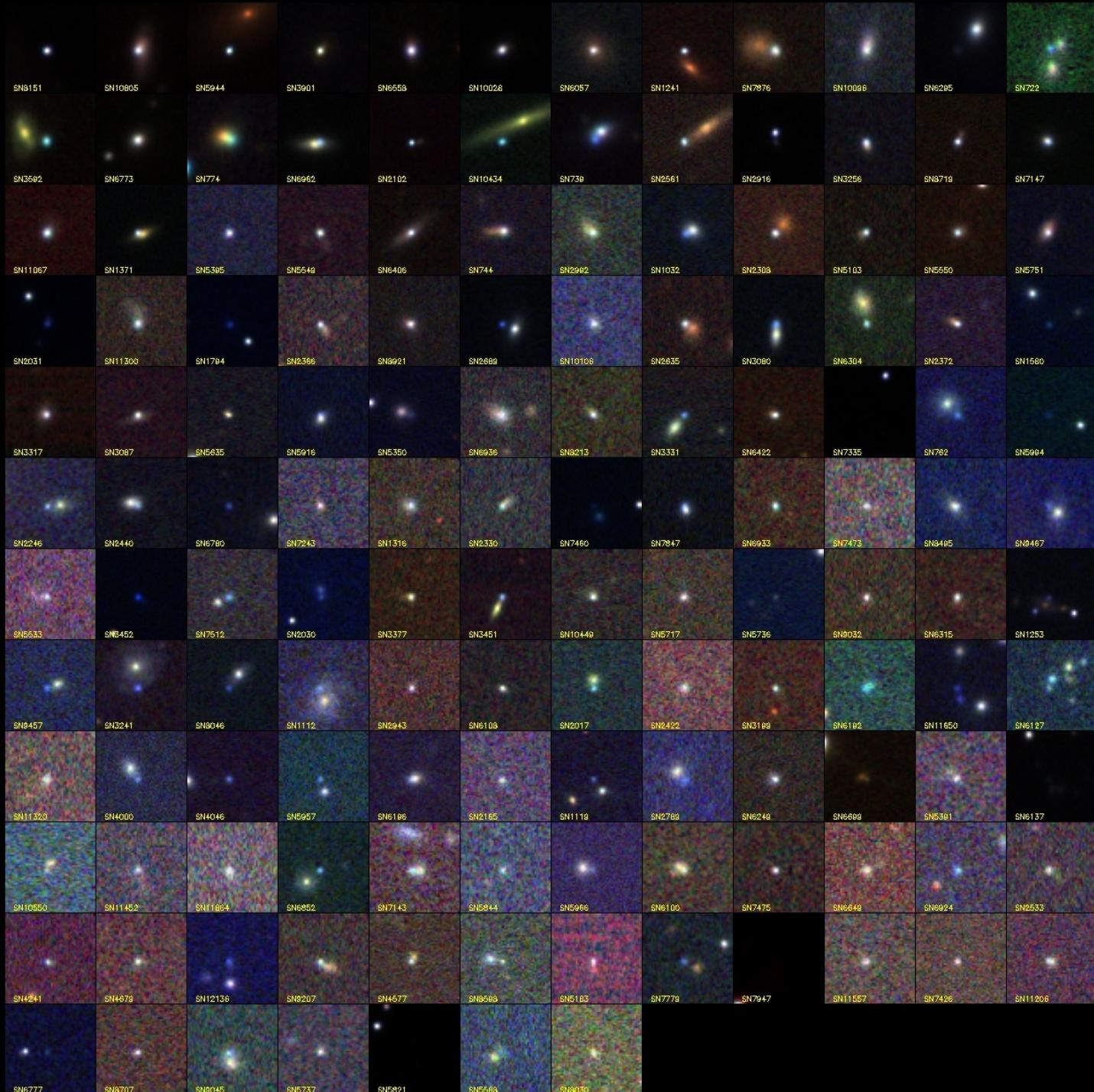


SDSS II first year  
supernova yield:

139  
spectroscopically  
confirmed Type Ia  
Supernovae  
from the  
Fall 2005  
Season

Analysis is  
underway

2 more years to go!



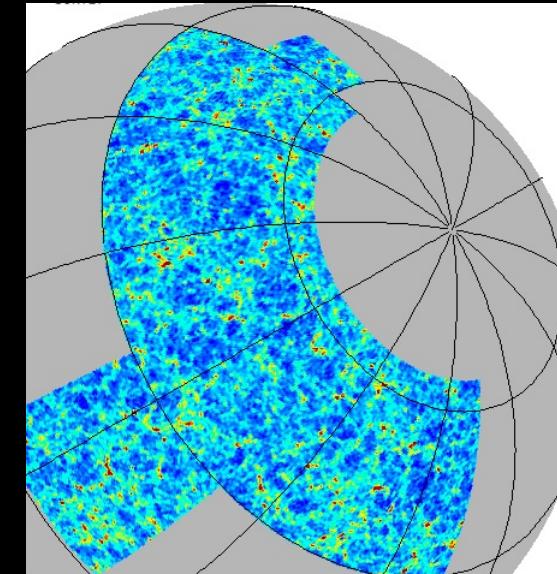
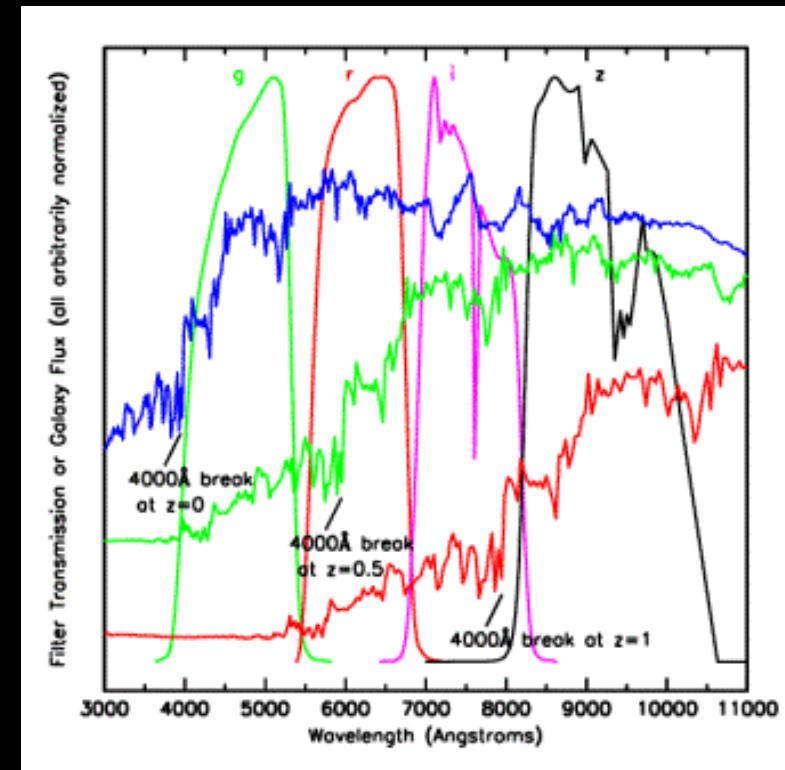
# Future projects

1. **Dark Energy Survey**  
*first light: 2009*

2. **SNAP**  
*first light: ~2015*

# Dark Energy Survey

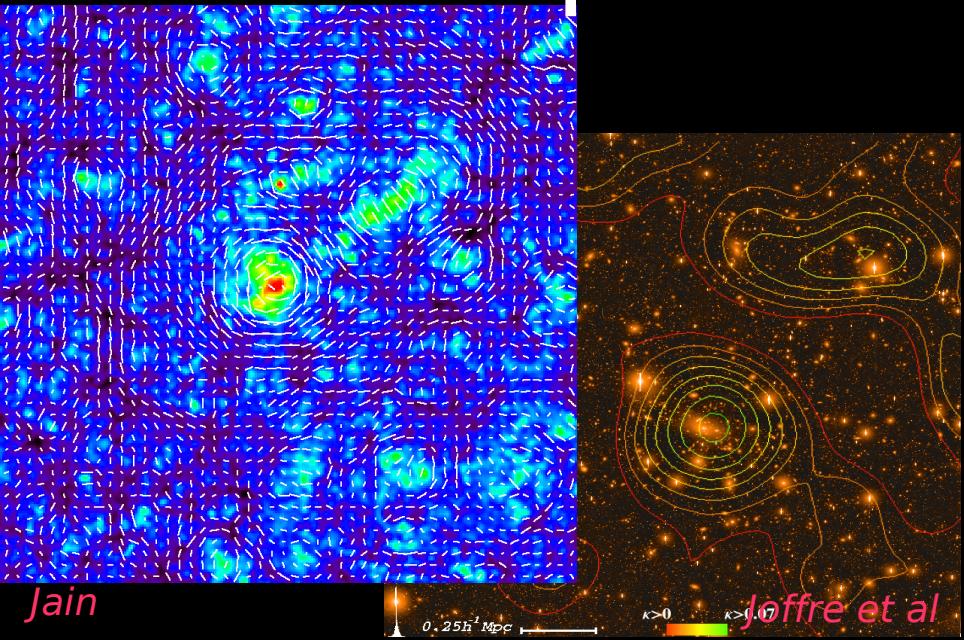
- What is Dark Energy?
  - Cosmological constant?
  - Scalar field?
  - Modification to gravity?
- Carry out a “photometric” redshift survey to study Dark Energy with **4 complementary techniques**
- Observe **5000 deg<sup>2</sup>** in 4 broadbands, in Southern hemisphere to overlap with CMB observations by South Pole Telescope
- Requires a new 62 CCD camera (much larger than any current instrument)



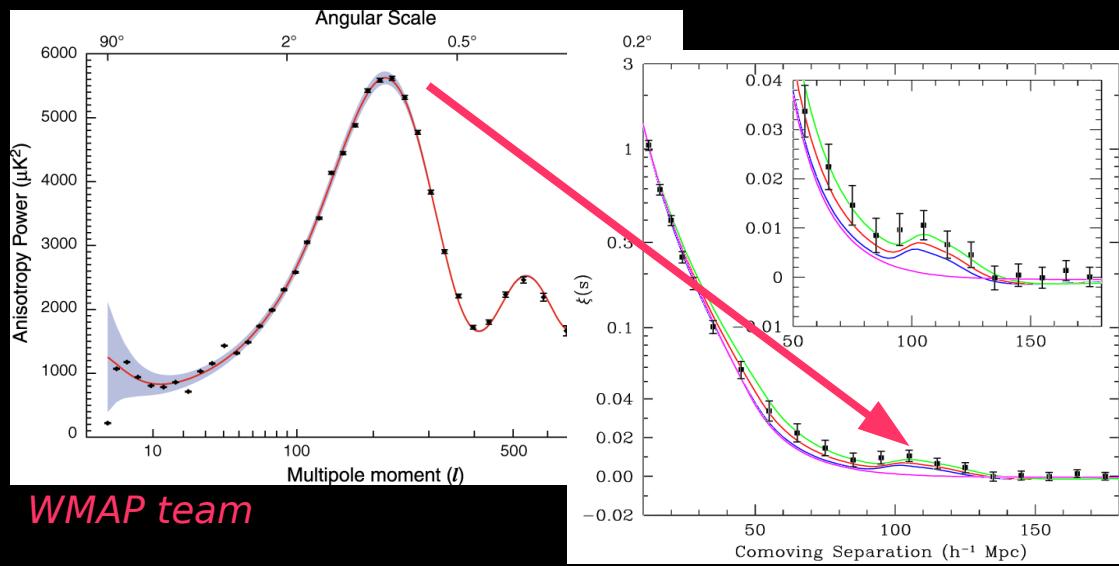
G. Miknaitis

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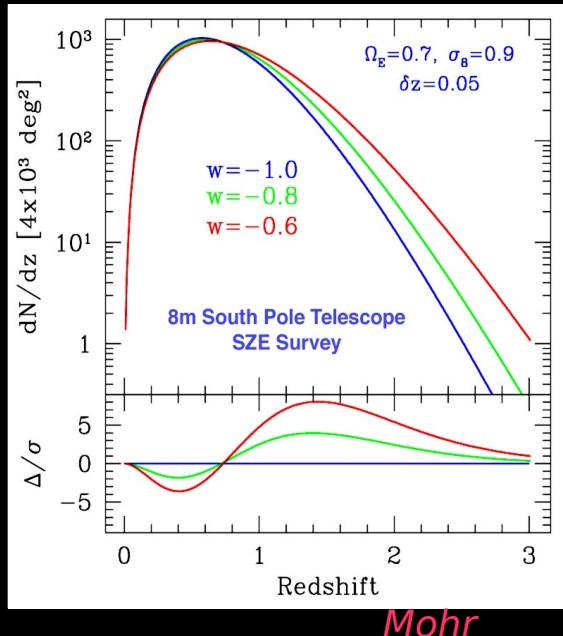
# Four probes of Dark Energy



1. Weak gravitational lensing



2. Baryonic Acoustic Oscillations



3. Cluster counts



4. Supernovae

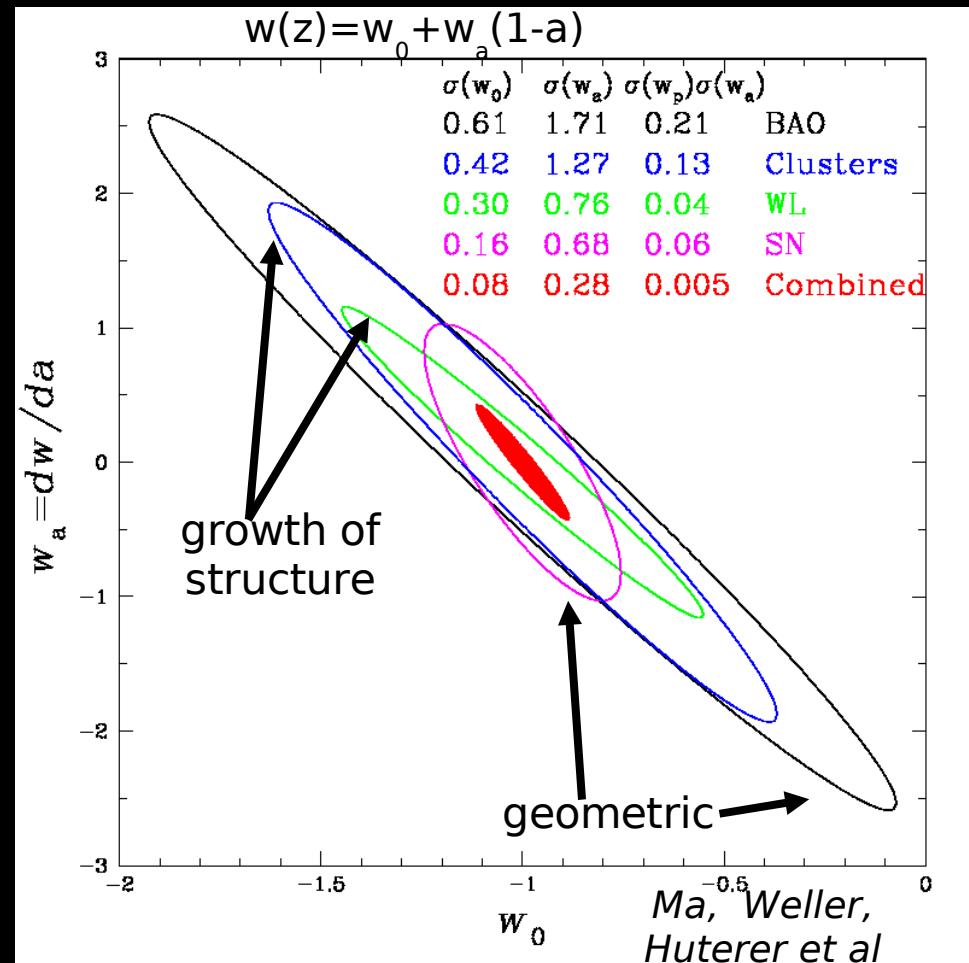
# Measuring Dark Energy with DES

## By the numbers:

- 300 million galaxies (WL, BAO)
- 10,000 clusters
- 2,000 supernovae

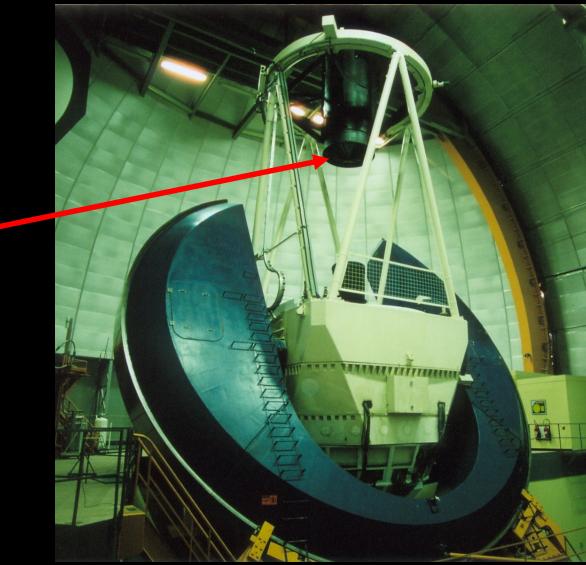
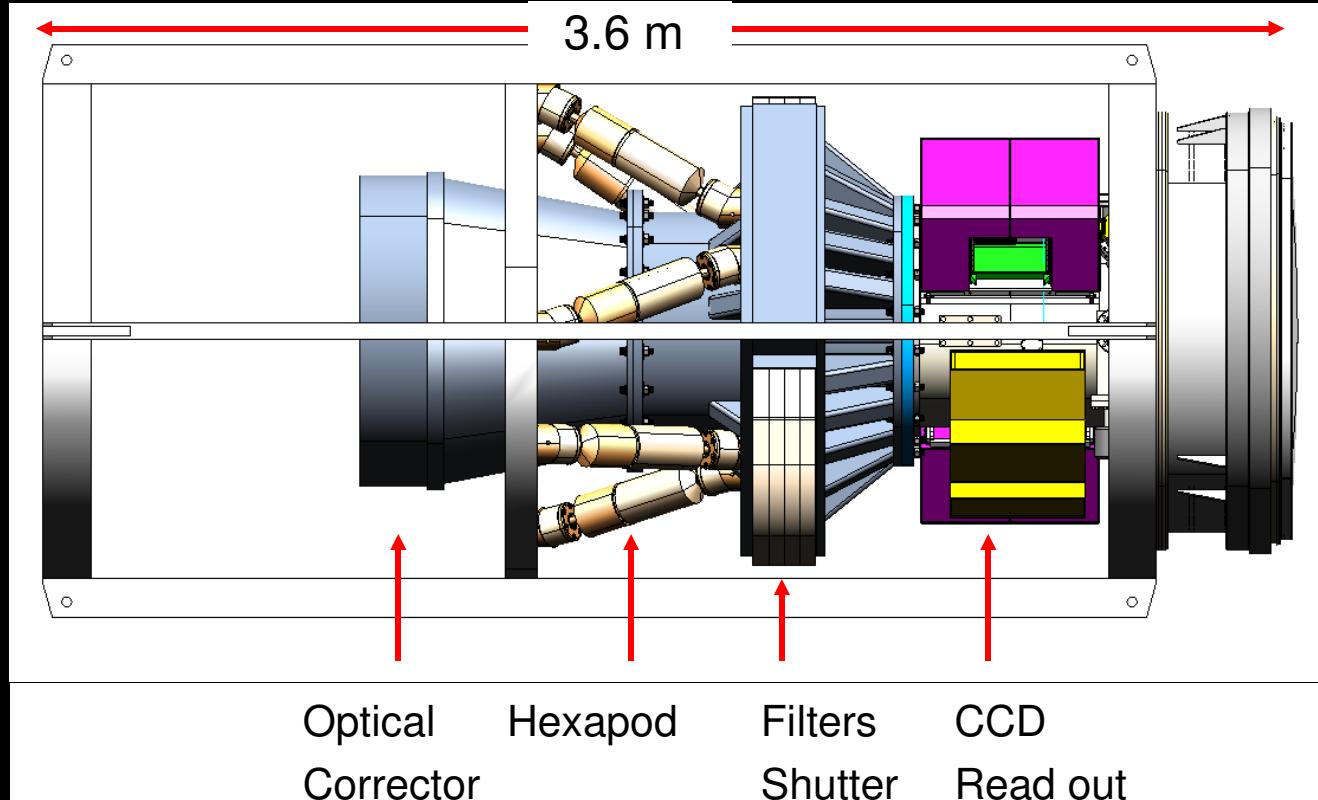
## Complementary probes:

- sensitivity to cosmological parameters
- systematic errors
- measures of physics
  - geometric probes
  - growth of structure



predicted DES constraints on the equation of state of dark energy,  $w$ , and its evolution

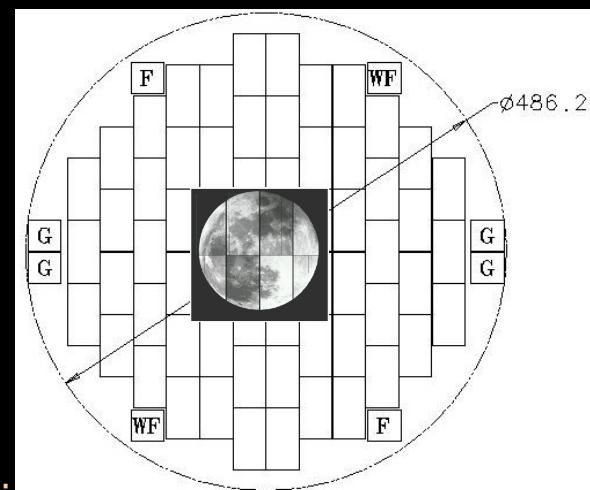
# The Dark Energy Camera

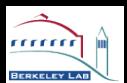


CTIO Blanco 4m telescope,  
operated by NOAO for the NSF

- Full depletion CCDs
- Very large focal plane
- Readout: 17s readout time, 10 e- noise
- 0.6m $\times$ 0.6m glass filters: g,r,i,z
- 5 element optical corrector

Focal plane:  
62 2k x 4k Image CCDs (520 Mpixels)  
8 2k x 2k Guide, focus, alignment CCDs





# The DES Collaboration

**Fermilab:** J. Annis, H. T. Diehl, S. Dodelson, J. Estrada, B. Flaugher, J. Frieman, S. Kent, H. Lin, K. W. Merritt, J. Peoples, V. Scarpine, A. Stebbins, C. Stoughton, D. Tucker, W. Wester

**University of Illinois at Urbana-Champaign:** C. Beldica, R. Brunner, I. Karliner, J. Mohr, R. Plante, P. Ricker, M. Selen, J. Thaler

**University of Chicago:** J. Carlstrom, S. Dodelson, J. Frieman, M. Gladders, W. Hu, S. Kent, E. Sheldon, R. Wechsler

**Lawrence Berkeley National Lab:** G. Aldering, N. Roe, C. Bebek, M. Levi, S. Perlmutter

**NOAO/CTIO:** T. Abbott, C. Miller, C. Smith, N. Suntzeff, A. Walker

**Institut d'Estudis Espacials de Catalunya:** F. Castander, P. Fosalba, E. Gaztañaga, J. Miralda-Escude

**Institut de Fisica d'Altes Energies:** E. Fernández, M. Martínez

**University College London:** O. Lahav, P. Doel, M. Barlow, S. Bridle, D. Brooks, S. Viti, S. Worswick, J. Weller

**University of Cambridge:** G. Efstathiou, R. McMahon, W. Sutherland

**University of Edinburgh:** J. Peacock

**University of Portsmouth:** R. Nichol

**University of Michigan:** R. Bernstein, B. Bigelow, M. Campbell, A. Evrard, D. Gerdes, T. McKay, M. Schubnell, G. Tarle, M. Tecchio

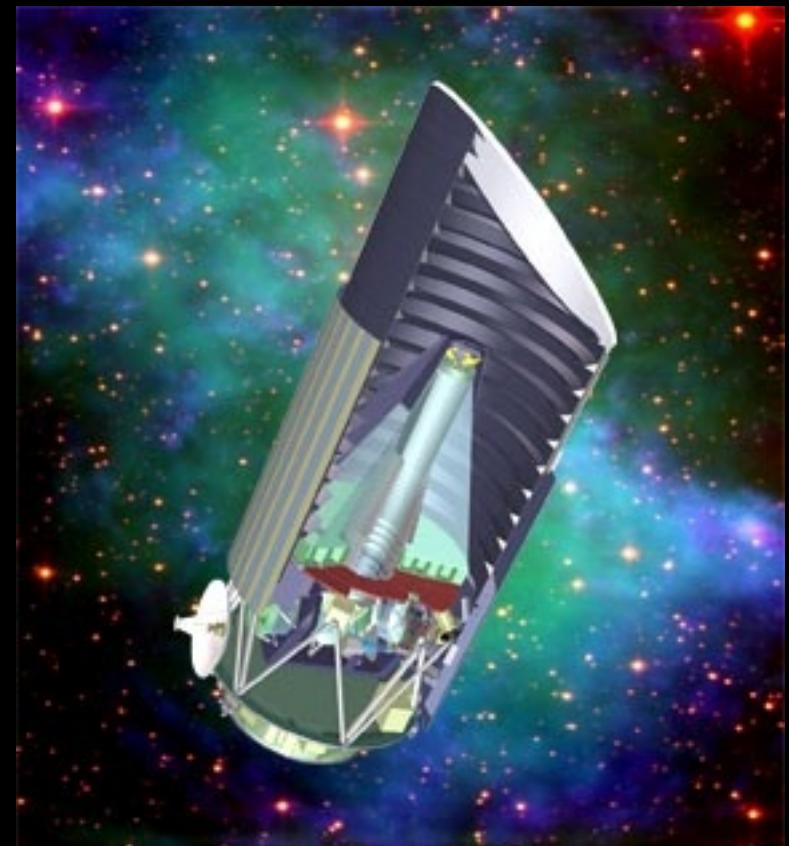
**Ciemat Madrid:** C. Mana, M. Molla, E. Sanchez    **UAM Madrid:** J. Garcia-Bellido



# SNAP: Supernova Acceleration Probe

LBNL, UC Berkeley, CalTech, FNAL, Indiana U, IN2P3/INSU (France), JPL, LAM (France), U Michigan, U Penn, U Stockholm, STScI, Yale

- High precision cosmology from dedicated space-based telescope
  - measurements of ~3000 supernovae to  $z=1.7$
  - weak lensing
- 9 filters, spanning 0.3-1.7  $\mu\text{m}$
- Spectrograph + Imager containing CCD and IR detectors for a total of ~600 million pixels



# SNAP at Fermilab

- **Electronics**

- Fermilab regulator IC (ASIC)
    - signal processing for IR chips,  
template/voltage control
  - Mass memory
    - flash for storage, FPGA for control, radiation  
damage testing

- **Simulations**

- Pixel-level image simulations

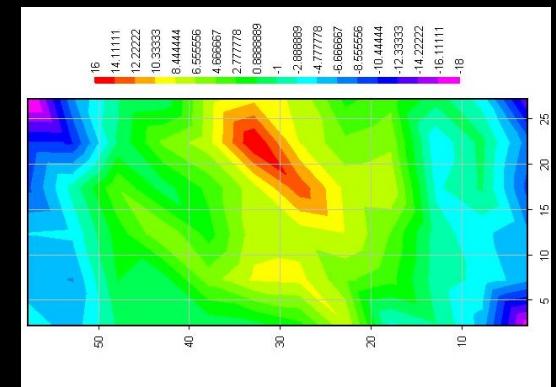
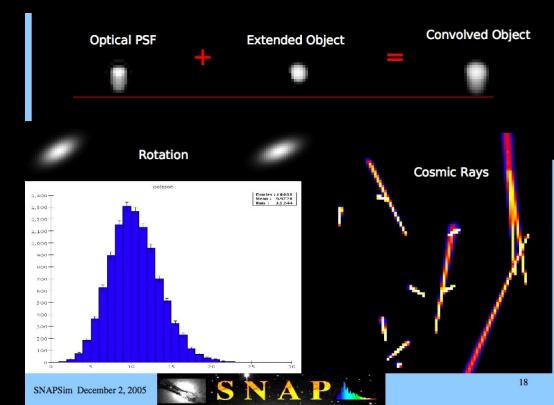
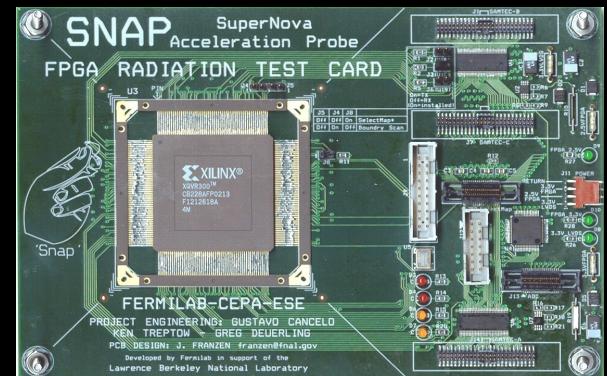
- Calibration

- Establish/observe SNAP photometric standard stars

- **CCD testing & packaging**

- **Cosmic Ray Shield**

## • Photo-z for Weak Lensing



# Summary

Fermilab is engaged in a variety of exciting observational astrophysics and cosmology projects

SDSS is the world leader in studies of large scale structure of the universe (and many other fields of astronomy)

SDSS-II will enhance our understanding of two of the today's greatest mysteries in cosmology:  
**Dark Matter** and **Dark Energy**

In the future, DES and SNAP will provide precise constraints on the nature of Dark Energy